Operation of Tube Mills

Hp. Fisch
VA 89/5588/E

1. INTRODUCTION

Grinding systems with tube mills have been operated throughout the world for many decades. Many practical ways to operate these mills in an easy way have been developed and many improvements introduced, including the application of new technologies.

But still, the operation of tube mills involves a large number of items and routines which importance often is not sufficiently considered by the responsibles. Many times a great deal of facts are neglected and even fundamental procedures are unconcernedly carried out, leading to constant drawbacks.

Any grinding system should be operated in such a way as to obtain the necessary product quality and to achieve the maximum mill output. As soon as an efficiency drop is observed then the reasons should be investigated. There are many different grinding systems and **each system underlies its own and specific conditions.** It is obvious that no standard instruction can be given for all possibilities and cases. This paper serves as general guide line for better mill operation and the procedure of practical mill assessment.

In a cement plant, the largest portion of electrical energy costs is related to cement grinding. Any improvement in grinding efficiency results in considerable savings. Subsequent guide lines refer therefore in the first place to cement grinding plants, where the procedure for raw mills and coal mills is similar and can be derived from this. Raw and coal mills include additionally the drying aspects which have to be assessed.

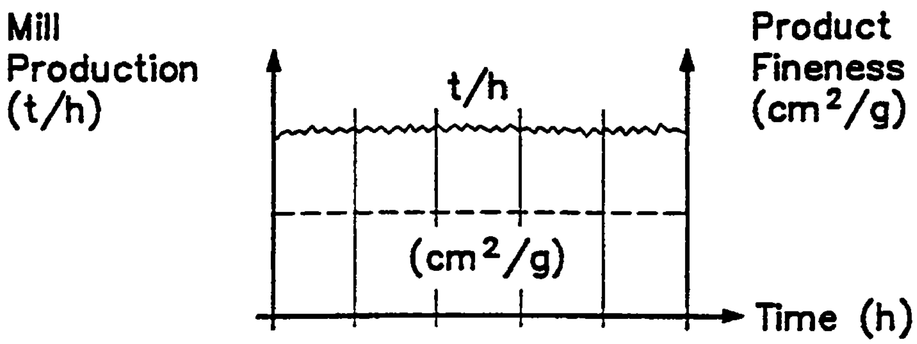
2. NORMAL OPERATION

Normal operation can be defined as the day to day operation of the mill system with a continuous mill output and a steady cement quality (fig. 1). Any common disturbance can easily be equilibrated with normal means of mill control, either manually or automatically with a closed loops control system.

Prerequisites for normal operation are

- well maintained equipment of the mill system with properly working control elements
- steady and normal feed material properties
- minimal interruptions in operation by external factors (lack of feed material, electricity failure, other shut downs, etc.)
- well trained mill operators and ev. a suitable, automatic mill control circuit

Figure 1 Normal Operation



Small variations of operating parameters within the system can be corrected by adjustment of the available control elements. The most common control elements are:

Figure 2 Adjustment Possibilities

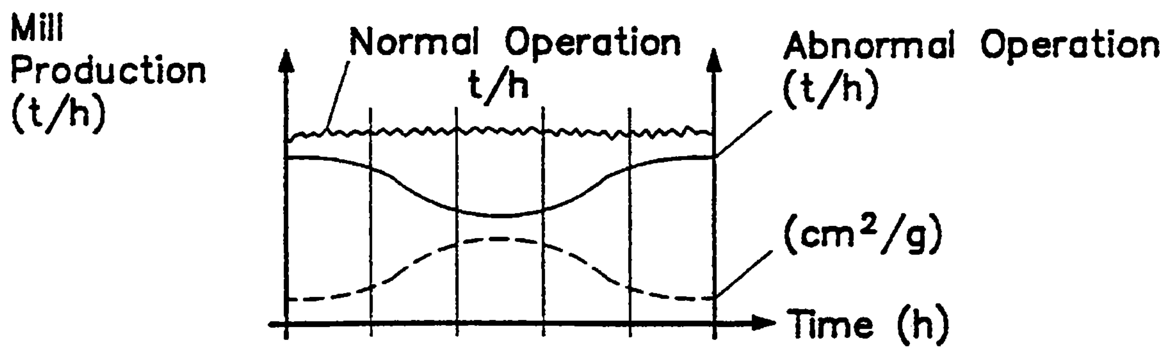
Control Element	Adjustment of	Effect on
Weighfeeder	Speed	Feed rate (= mill output) Proportions of components Circulating load
Separator	Rotor Speed Dampers Rotor Blades Fan Damper	Product fineness Granulometry Spec. surface Circulating load
Static Separator	Position of vanes	Granulometry of filter dust
Water Injection	Regulating valve	Mill discharge temp., Coating
Mill Venting Fan	Position of damper	Mill cooling, Dust granulometry

Conditions and parameters for normal operation have to be recorded for reference purpose.

3. ABNORMAL OPERATION

As abnormal operation can be defined all operating conditions beyond the normal range. In this case, either the required mill output rate and/or the required quality cannot be reached relative to the recorded normal operating conditions (fig. 3).

Figure 3 Abnormal Operation



Abnormal operating conditions can be caused by many different disturbances upsetting the continuous running. Disturbances might result from

- changes in feed material properties
- Equipment problems (mechanical or process technological)
- Deficiencies of control elements
- Sensing element deficiencies (signal transmission errors etc.)
- External effects

As soon as deviations from the normal operation are encountered, the possible reasons have to be assessed in order to undertake necessary measures for correction. Often an abnormal operation can be counteracted by corrections through corresponding actions of the mill operator or the maintenance crew. If normal operation can not be reestablished by such procedures, the execution of a performance test of the mill system is indicated.

Fig. 4 gives a general check-list to find the possible reasons and, to a certain extent, the possibility of taking first actions. In some cases it is not adequate to take individual actions because the problems are more complex. Only a performance test of the entire grinding system with a subsequent evaluation will reveal the overall problems.

Figure 4 Check-list 'Abnormal Operation'

INDICATION	POSSIBLE REASON	ACTION
Product:		
too coarse	Mill overfilled Separator adjustment Mill feed very coarse Filter dust too coarse	Low mill feed rate Proper adjustment Improve precrushing Adjust static separator / Venting rate
too fine	Mill underloaded Separator adjustment Mill feed very fine Filter dust very fine	Increase mill feed rate Proper adjustment Further investigation required Adjust static separator / Venting rate
wrong chemical composition	Wrong feed proportions Wrong feed components	Adjust proper proportions Change component quality
Mill: *)		
sound dull	Mill overfilled	Lower mill feed rate
sound loud	Mill underloaded	Increase mill feed rate
Cement Temperature:		
too high	Clinker temp. too high Low mill / separator venting Lack of water injection Cement cooler failure	Check clinker cooling Adjust venting rate Adjust flow rate Mechanical replacement Repair
Mill Output:		
too low	Unsuitable ball charge composition or badly worn balls Diaphragm unsuitable or clogged Unsuitable or worn liners Change of feed grindability Coating of balls Adjustment of separator Operators error	Change ball charge Replace or clean diaphragm Replace liners Further investigations required Improve cooling / use grinding aids Adjustment Instruction / training
Mill Exhaust Pressure:		
too high	Inlet / outlet clogged Diaphragm clogged	Clean Clean diaphragm
too low	Diaphragm broken Major false air penetration	Replace broken plate Seal sources

*) same applies for Elevator Amps and reject rates from separator

4. PERFORMANCE TEST

4.1 Purpose

Performance tests should be carried out on following occasions:

* After start-up of a new mill to verify the guarantee figures
* Poor performance of a grinding system; low mill output or poor product quality
* High operation or maintenance cost
* Implementation of new processes and techniques, e.g. roller press, new separator, new control circuit
* Planned capacity increase, e.g. in connection with increased clinker production, reduction of grinding hours (utilization of low tariff hours)

The results of performance tests could be expressed in terms of efficiencies which allow a **comparison** with other grinding systems and **reference values.** The results provide also the basic information for required changes or modifications within the mill system.

A complete mill performance test comprises basically the following work:

* Determination of mill output and power consumption
* Sampling within grinding system
* Sampling inside mill
* Gas flow measurements (volumes, pressures, temperatures)
* Recording of operational data
* Visual inspection of equipment
* Evaluation of test

The results provide also the basic information for required changes or modifications within the mill system:

- **Grinding efficiency** - improvement of mill internals (ballcharges, liners, diaphragms, compartment lengths, etc.), inlet and outlet arrangement
- **Separator efficiency** - improvement of separator system (separating air flow, dedusting, mechanical adjustments, etc.)
- **Cooling resp. drying efficiency** - adjustment of air / gas flows, adaptations of dedusting systems
- **Weak point analysis** - find points which limit the system performance (sizing and type of equipment, operating ranges)

The experience shows that this last point gains more and more importance with the implementation of new techniques, where often many existing items form a bottle-neck in the mill production.

4.2 Measurements

4.2.1 Mill Output

The determination of mill output G [t/h] is one of the most significant factors for the performance of a mill system.

Methods for output measurement:

- **Indications from weighfeeders or belt scales**
  The most accurate values are the readings of totalizers T (accumulated [t]) and time measurement t [h] during the test period resulting in [t/h]. Instant readings may be used for reference purpose.
  The weighing facilities have in any case to be calibrated prior to start of tests.
- **Table feeders**
  The feed to the mill is bypassed for a short period, weighed and then returned to the mill. The test has to be done several times. No adjustments of the feed rate should be made during the test.
- **Silo measurement**
  The tonnage between two silo filling levels in relation to the recorded operating time gives and indication of the mill output. The variable material density can be based on experience values.

4.2.2 Energy Consumption

It is in most cases sufficient to determine the energy consumption of:

* Mill
* ev. Roller Press
* Auxiliaries
* Total Mill System

During the test period the energy readings from totalizers E (accumulated [kWh]) as well as the time t [h] is recorded. The division of the values is then an average absorbed power P [kW]. The relation to the measured mill output G [t/h] indicates the spec. energy consumption q [kWh/t].

$$q = P\,[\text{kW}] / G\,[\text{t/h}] = [\text{kWh/t}]$$

or

$$q = E\,[\text{kWh}] / T\,[\text{t}] = [\text{kWh/t}]$$

Cross checks for the power input to the mill drives can be made under utilization of the mill formula, calculating the mill power on basis of the mill dimensions and ball charges.

4.2.3 Temperatures, Air-flow and Pressures

Product:

Significant are mainly the temperatures of clinker, of mill discharge product and of the cement before the silos. These values are utilized to perform a heat balance and to judge process technological phenomena.

Air:

Of prime interest is the performance of the mill ventilation and, in an increasing way, also the separator. Fig. 5 shows the typical measuring points:

Figure 5 Air Measurement Points

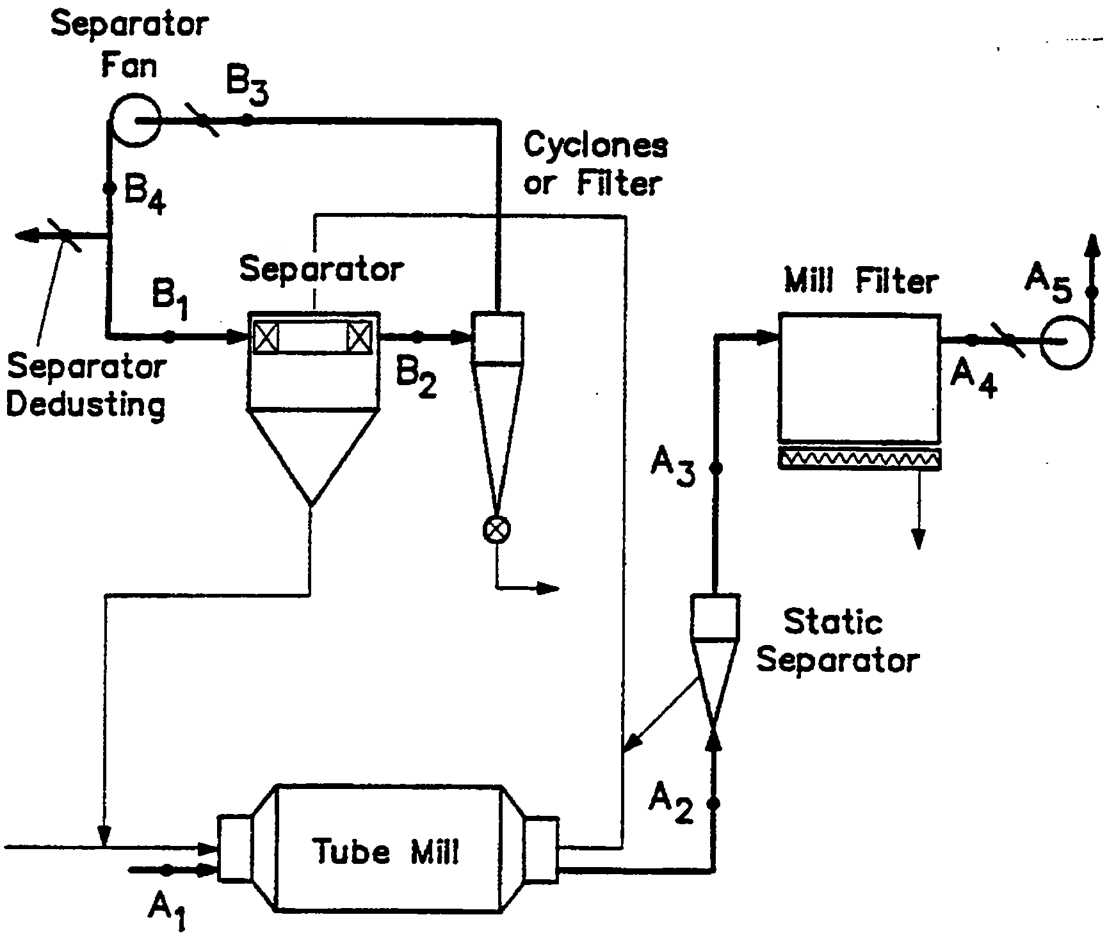


Figure 6 Type of Air Measurements

Mill Ventilation		
Points	**Pressure drop**	**Measurement**
A1 Ambient	Δp mill	T, pa
A2 Mill exit	Δp static sep.	T, p
A3 Static sep. exit	Δp filter	T, p
A4 Filter exit	Δp fan	T, p, $\dot{V}$
A5 Fan exit		T, p

Separator Venting		
B1 Ambient / Inlet	Δp separator	T, pa
B2 Separator exit	Δp cyclones	T, p
B3 Cyclone exit	Δp fan	T, p, $\dot{V}$
B4 Fan exit		T, p

Symbols:
T - temperature
p - static pressure
$\dot{V}$ - air flow rate

4.2.4 Operational Data

During the performance test also the operational data have to be recorded. This can be done on an hourly basis:

Possible operational data are:

- **Mill**
  Absorbed power, mill feed rates;
  Water injection rates, grinding aids (- ev. checking via bypass measurements), mill sound levels
- **Separator**
  Rotor speed, damper and vane positions (number and position of auxiliary blades), absorbed power of each drive (including fan)
- **Static separator**
  Position of vanes
- **Mill ventilation**
  Absorbed fan power, position of dampers, pressure indications, filter data
- **Conveyors**
  Absorbed power of bucket elevator, pneumatic transport data

4.3 Sampling

To assess the performance of the grinding system, it is important to know the exact granulometry of the individual material streams within the grinding circuit. Prerequisites for a reliable sampling during the performance test are

* Stable operation of the mill system
  (begin sampling earliest 6 - 8 h after start of cold mill)
* 6 - 12 h duration of performance test
* Taking samples from the system every 1/2 to 1 h

4.3.1 General Sampling Routines

Prior to the performance test, the exact sampling points have to be determined. The sampling points have to be selected in such a way as to make sure that the sample is representative for the entire material flow in that location. That means, it has to be avoided that

- part of the sample (the fines) is swept away by dedusting air.
- material from another source is partly collected with the sampler.

Suitable samplers must be provided for the corresponding location to assure an acceptable representativity of the sample.

It is often not possible to find a suitable sampling location which fulfill the requirements.

4.3.2 Sampling within the Mill System

Possible sampling points within a cement grinding system are shown in fig. 7 and the required quantities and sieve analysis in fig. 8.

Figure 7 Sampling Points with Mill System

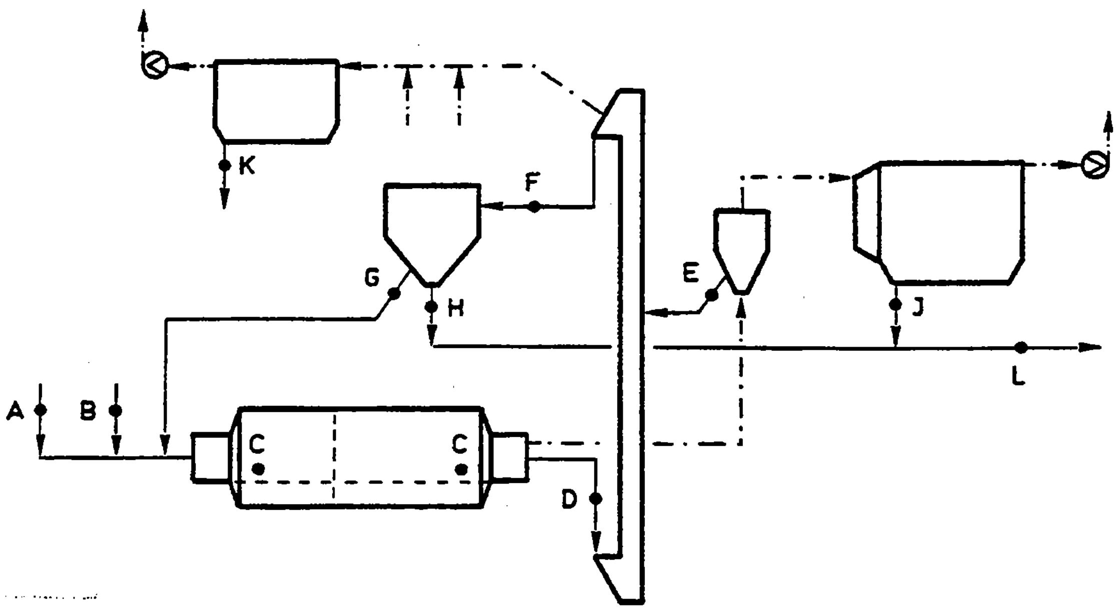


Figure 8 Sample Quantities and Analysis

Sampling point	Weight	Required sieve analysis
A/B Mill feed	10 kg each	e.g. 30, 25, 16, 8, 4, 2, 1 mm
C Samples within mill	See longitudinal sieving	
D Mill discharge E Separator tailings	0,5 kg	e.g. 30, 60, 90, 150, 200 µm Blaine
F Separator feed G Separator tailings H Separator fines	0,5 kg	e.g. 4, 8, 15, 20, 30, 60, 90, 150, 200 µm Blaine
J Filter dust K Filter dust	0,5 kg	e.g. 30, 60, 90, 150, 200 µm Blaine
L Final product	0,5 kg	e.g. 4, 8, 15, 20, 30, 60, 90, 150, 200 µm Blaine

Individual samples from each sampling point are collected during the period of performance test and a composite sample formed per point. These samples have to be homogenized and splitted to the required sample of 0.5 kg for the sieve analysis and Blaine measurement.

Samples from the mill feed components have to be taken once only. Depending on the additives used, also the moisture contents of these additives have to be determined.

4.3.3 Longitudinal Sampling

The grinding efficiency of a tube mill is influenced by a series of factors, e.g.

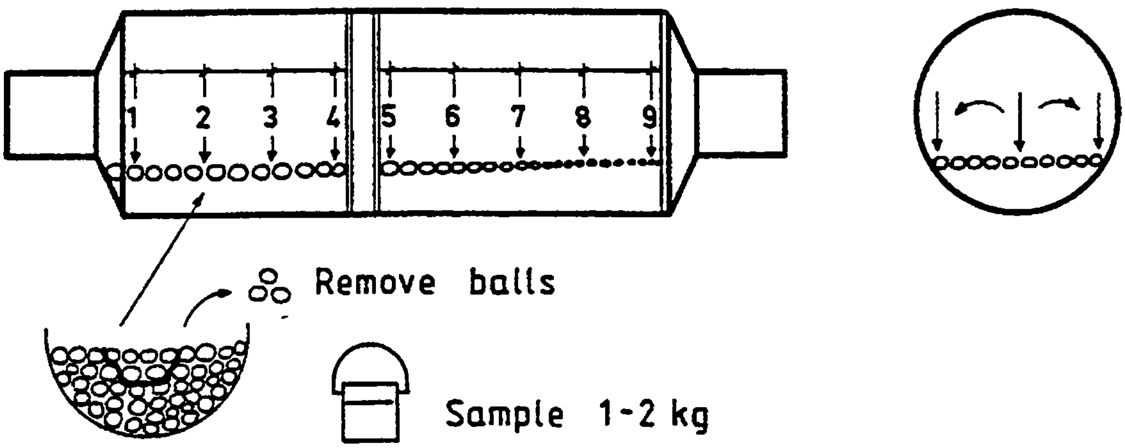
- Mill type (and mill system)
- Feed material properties
- Ball charge composition
- Filling degrees, mill speed, shape of liners
- Compartment lengths (in conjunction with cement type and circulating load)
- Diaphragms, type and mechanical conditions
- Mill ventilation (air speed inside mill)
- Temperature and moisture content of feed material

The best indication of the grinding efficiency and how the mill gets along with all these factors gives a longitudinal sampling test that means the sampling within the mill. For this purpose following procedure should be observed:

- Stable operation of the mill system for some 10 - 12 h
- The performance data prior to this sampling have to be recorded as described before
- Preparation of required sampling equipment such as metal cans (properly marked), light sources, measuring tapes, shovels, etc.
- The mill and all auxiliary equipment have to be stopped (emergency stop) to be sure that the conditions inside the mill remain unchanged. The shut down of the mill ventilation is important to avoid that the fines from the mill discharge are swept away.
- Before entering the mill, the necessary safety measures should be taken (disconnect **main circuit breakers**)

4.3.4 Sampling Procedure

Figure 9 Sample Taking



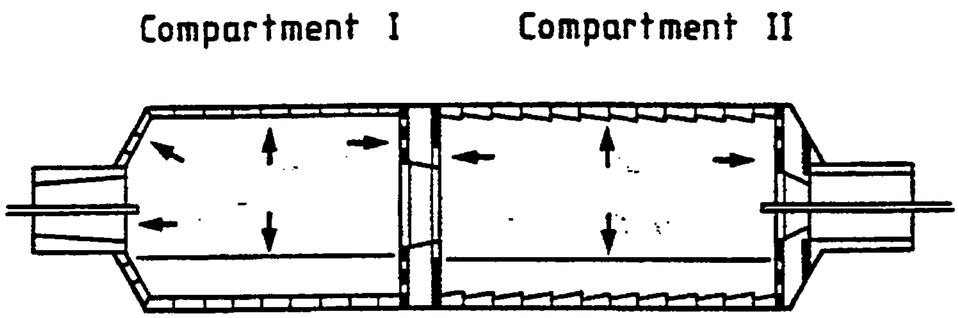
Each sample should be collected from three points in the same cross section of the mill and weigh 1 - 2 kg. To get a representative sample some balls should be removed and the material taken from inside the charge.

One composite sample each 1 m along the mill axis should be taken. The first and the last sampling point should be 0.5 m off the wall / diaphragm as there are often some retained particle fractions or segregated material leading to unrepresentative samples.

Parallel to this sampling inside the mill also a visual inspection should be performed.

4.3.5 Visual Inspection

Figure 10 Visual Inspection within Mill



Following items should be checked within the mill to give important hints on the grinding efficiency:

4.3.6 Material Level and Distribution

The material should be evenly distributed over the ball charge in both compartments. The material level should be:

- **1st compartment**: balls just visible, at the inlet an accumulation off material could be possible.
- **2nd compartment**: balls entirely covered by a material layer of about 20 - 30 mm.

4.3.7 Grinding Media and Charge

Necessary checks are:

- Measurements of height above charge and internal mill diameter as well as exact compartment lengths (d_i, h, l_i) for recalculation of filling degree and absorbed mill power
- Ball sizes and their distribution along the mill axis (especially in mills equipped with classifying liners)
- Shape and conditions of grinding media (worn and/or broken media) as well as foreign bodies (metal scrap) in the charge
- Formation of coating around the grinding media

4.3.8 Shell Liners and Diaphragms

- Conditions, shape and remaining thickness of liner plates. Formation of coating
- Conditions of blind plates (wear)
- **Diaphragms**: Size and shape of slots, conditions and remaining thickness. If the slots are blocked, cleaning will be necessary, eventual screening out of the scrap in the media charge might be indicated. Gaps between slot plates and deficiencies in the center grates should be repaired.

4.3.9 Water Injection Nozzles

The nozzles should always be open and clean, no damages from impacts. Obstructions with material can be avoided by proper control of the cleaning air in the waterspray system.

4.3.10 Sample Analysis

From each sample a sieve analysis has to be carried out:

Figure 11 Sieves for the Longitudinal Sampling Analysis

1st compartment	Sieves 16, 10, 6, 2, 1.25, 0.5, 0.2 [mm]
2nd compartment	Sieves 1.25, 0.5, 0.2, 0.12, 0.09, 0.06 [mm] Blaine [cm^2/g]

Often not representative results are gained from the sieve analysis when metal parts are not separated prior to sieving or when the homogenizing and the dividing of the composite samples are not properly done.

4.4 Inspections

Besides the visual inspection within the mill at the occasion of the longitudinal sampling, the entire mill system should be inspected in view of mechanical as well as process technological aspects. In many cases the real bottle necks can be detected just by observing closely the mill operation.

Some examples:

* Limited capacity of feeders or conveying elements
* Wrong readings from such elements resulting in incorrect mill control
* Mechanical deficiencies (wear!)
* Insufficient material flows or flow divisions
* Air flow problems and dedusting deficiencies, blockages
* Not representative sampling

5. EVALUATION OF PERFORMANCE

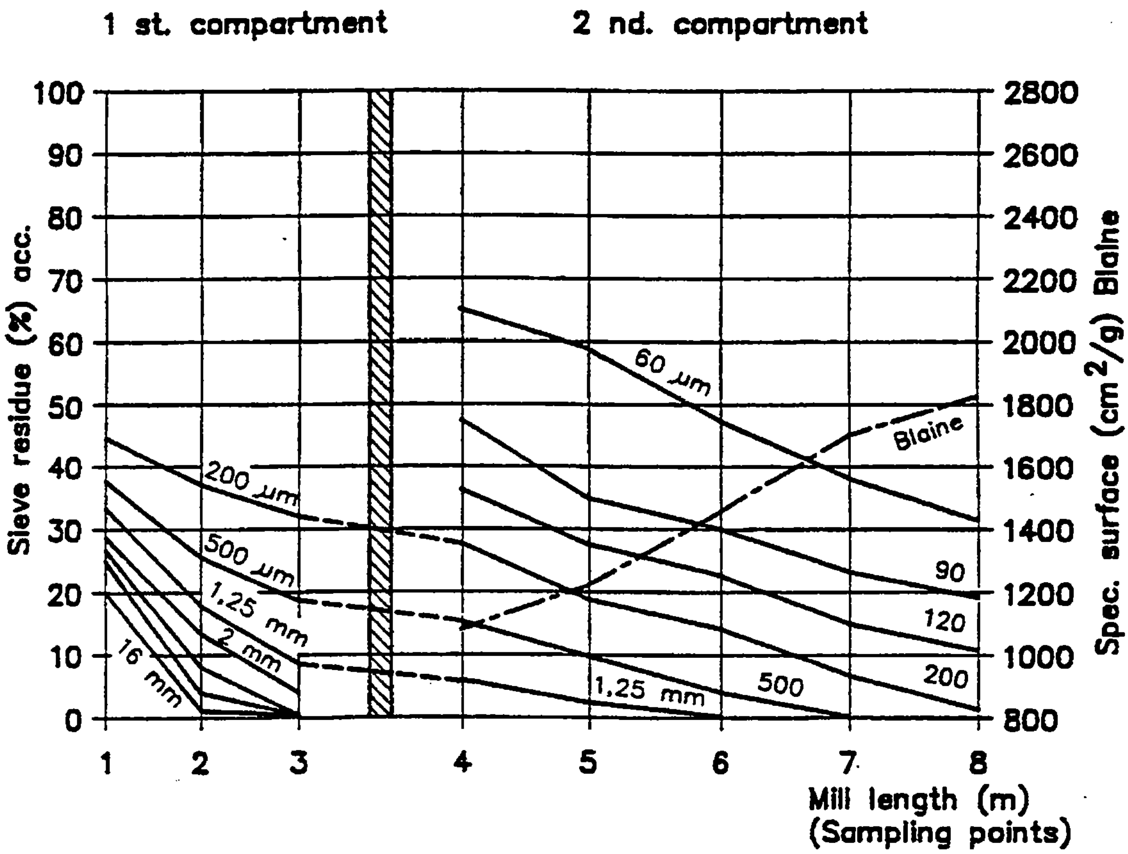
5.1 Interpretation of Test Results

The interpretation of the test results is very much a matter of experience and training. Who is less experienced takes guide lines and general indications for reference. Subsequently some basic guide lines are given. More indications are available in the respective sections of this documentation.

5.1.1 Grinding Efficiency

The main tool for judgment of the grinding efficiency is the grinding diagram as a result from the longitudinal sieving. A sample plot is given in fig. 12.

Figure 12 Typical Grinding Diagram for a Two-Compartment Cement Mill



Above diagram is typical for a two-compartment cement mill in closed circuit producing an ordinary portland cement with a fineness of ~ 3000 [cm^2/g] Blaine.

For a judgment of the diagram usually the sieve residues and the Blaine value in front of the diaphragms are used. Reference values are:

- In front of **intermediate diaphragm**:
  15 - 25 % R 0.5 [mm]
  max. 5 % R 2.0 [mm]
- In front of **discharge diaphragm**:
  15 - 25 % R 0.09 [mm]
  max. 5 % R 2.0 [mm]

In case the results are not in line with these values, the possible reasons have to be analyzed in connection with all other findings from the performance test. Some of the possible correcting measures are listed in fig. 4.

5.1.2 Separator Efficiency

Good means for a judgment of the separator efficiency are:

* Trompcurve
* Separating efficiency curve
* Spec. separator loads

which can be computed on basis of analysis and measurements from the performance test (see section: separators).

5.1.3 Dedusting / Cooling Efficiency

Judgment criteria are mainly:

* Massflow / Gasflow measurements
* Dust granulometry
* Heat balances

established on basis of performance test results (guide lines see: mill ventilation and cement cooling).

6. GRINDING MEDIA CHARGES

The grinding media charge has a major impact on the grinding efficiency, due to:

- Charge conditions (worn media)
- Charge compositions (media grading)

6.1 Charge Conditions

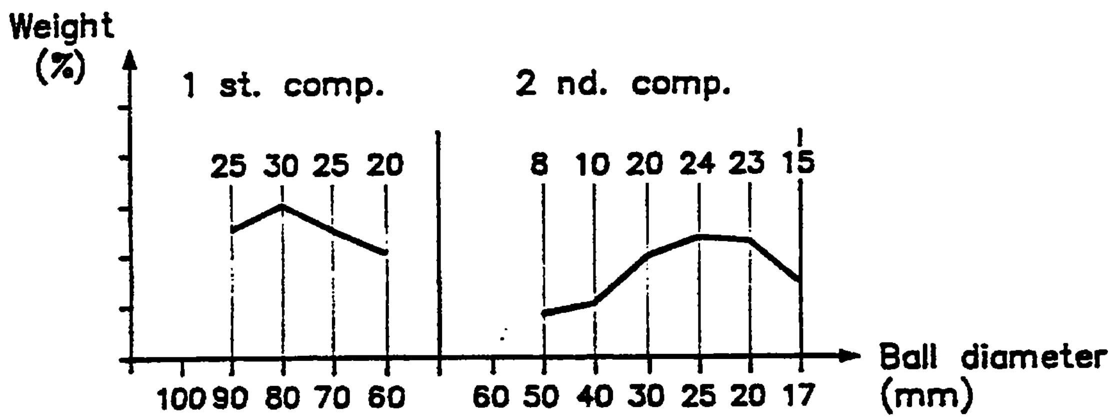
Badly worn grinding media change the grinding behavior that means it may lead to a different grading of the charge, influence the retention time of material through the mill, disturb the classifying effect in the 2nd compartment and if completely worn down obstruct the diaphragm slots. Therefore conditions of media charges have to be checked on a regular basis and the charge if necessary replaced.

6.2 Charge Composition

The correct charge composition depends on may influencing factors and has to be individually adapted in every case. Also quite different philosophies to determine grading and top size media are applied. Still, to compose a media charge is a matter of experience which so for could hardly be replaced by computer programs.

The main basis for the determination of media charge is the grinding diagram and the overall results of the performance test. The composition of the charge has to ensure an optimal grinding progress within the mill and the correct circulating load in a closed circuit. Usually various cement types are produced with one mill and the media composition is adapted to the type which is produced in larger quantities. Fig. 13 shows a typical media charge composition for a two-compartment cement mill in closed circuit for an OPC of ~ 3000 [cm^2/g] Blaine.

Figure 13 Typical Media Charge Composition



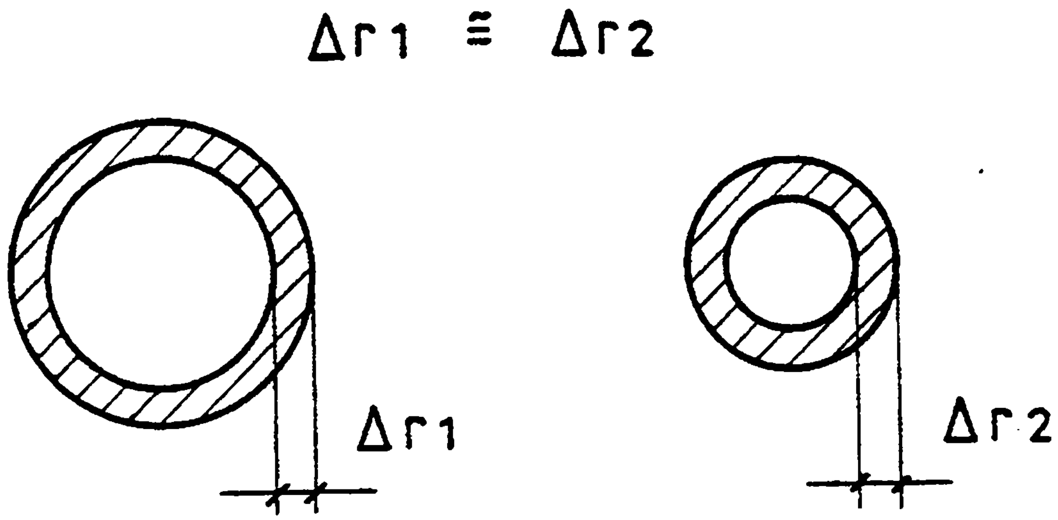
It is good routine to determine a certain media charge composition and first fill in only 80 % of the final charge weight. With this reduced charge a longitudinal sieving can be performed. According to the results of this test, the remaining 20 % of charge can still be corrected and filled in to reach an optimal adaptation.

6.3 Replenishment

Replenishment with grinding media to make up for wear should take place on a regular (running-) time basis (according to the wear rate) and reduction of power consumption. Depending on the criteria applied for the determination of the media charge composition the replenishment method has to be selected. For equilibrium charges only the largest media size of each compartment is needed whereas for a different charge composition portions of the two largest sizes or even more might be necessary to replenish the media charge to the desired weight.

Generally the wear of grinding media proceeds in such a way that the diameter reduces the same amount for any media size as shown in fig. 14.

Figure 14 Wear Pattern of Grinding Media



6.4 Recharging

In spite of all theories describing the wear procedure of grinding media it is hardly possible to maintain a determined and optimal media charge over a longer period of operation. It is therefore necessary to discharge the media from time to time and regrade the grinding media. A new grinding media charge can then be put back into the mill where the undersize media and the scrap is sorted-off.

Depending on the wear rate as a function of the specific conditions in grinding system, recharging should be done at least once every or once in two years.

In a second compartment with classifying lining the smaller size grinding media should be filled in close to the discharge end and the larger ones close to the inlet end of the compartment to favor the initial classifying effect. In larger mills a material cushion should be filled in prior to recharge the grinding media for protection of the linings.

7. OPTIMIZATION MEASURES

7.1 Short-term Measures

In most cases immediate adaptations can be carried out by the own maintenance crew under utilization of available equipment and spares from the plant. The measures are very economical as a certain success can be achieved with low costs.

7.2 Medium-term Measures

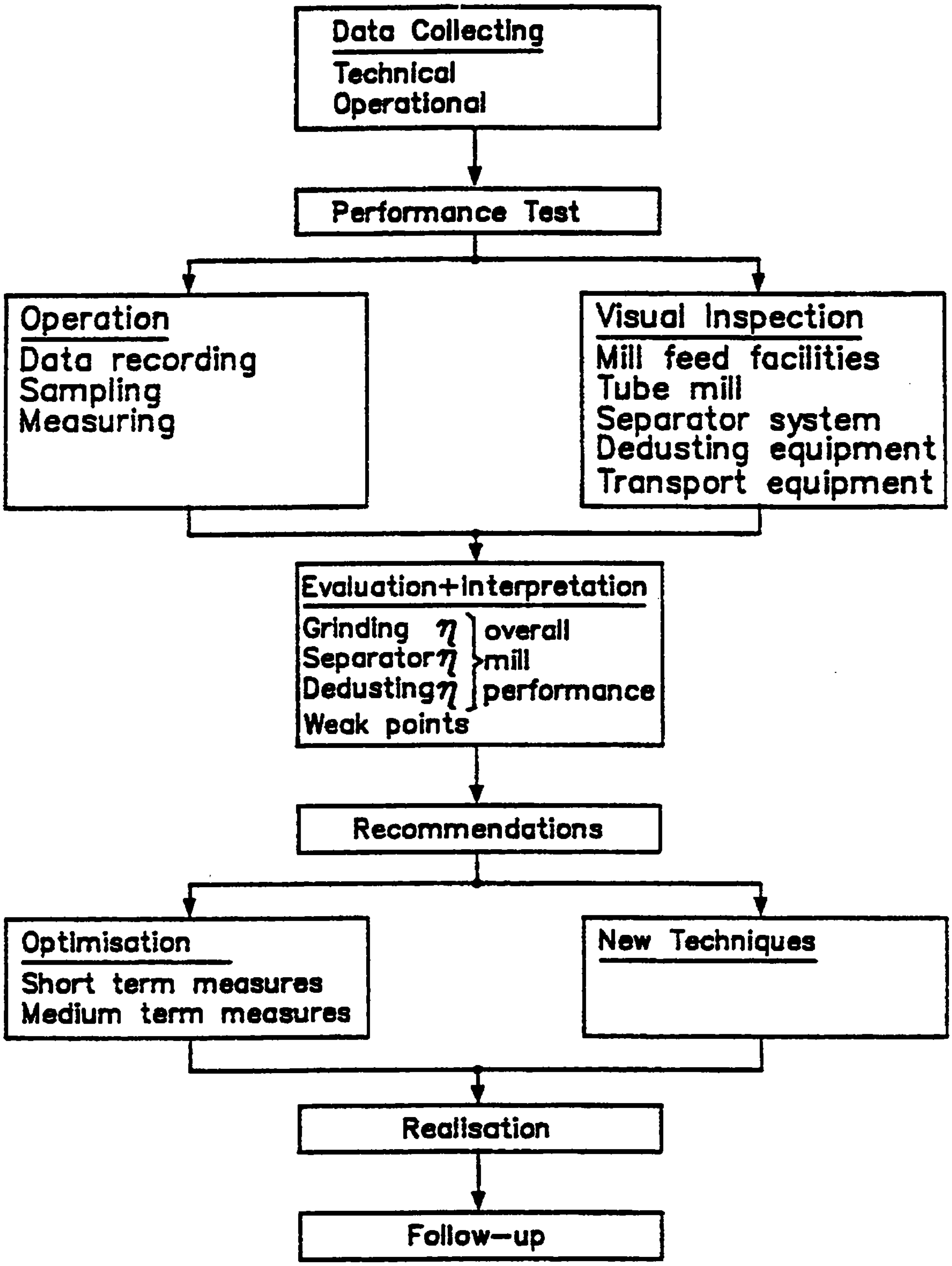
Larger modifications require usually more detailed investigations and discussions with specialists. Delivery times of parts and equipment lead to more extended project periods. It is obvious that such modifications call for some investments and that is where many optimization programs come to stop. It is then the engineers duty to convince the management of the advantages of such optimization measures!

7.3 New Technologies

The fast development in grinding technologies lead often to a point where investment for a new equipment is more advantageous than a modification. Respective investigations may answer the economical aspects of such measures.

Fig. 15 shows the procedure for the execution of a mill optimization program.

Figure 15 Mill Optimization Procedure



8. START-UP OF A NEW MILL

The start-up of a new tube mill should be done in several steps with increasing grinding media charge fillings and running in times. The steps can be summarized as follows as a general rule for cement mills:

Figure 16 Steps for Running-in Procedure

Step	% of charge	Running time	Media size	Observations
1	5	15 min.	max. 70 [mm]	
2	50	25 hours	max. 70 [mm]	with material feed
3	75	75 hours	max. 80 [mm]	with material feed
4	90	100 hours	max. 90 [mm]	with material feed
5	100	---	---	normal operation

Prior to charging the mill with grinding media, an amount of material should be filled in for protection of the liners. It is also essential that the mill is not running without material feed except for the first 15 minutes.

During the start-up period the bolts for liner fixation should be retightened several times, for the first time after 8 - 12 running hours.

9. BIBLIOGRAPHY

1) Verein Deutscher Zementwerke
Rohrmühlen und Mahltechnik
(VDZ-Merkblatt MT 22, 1961)

2) K. Breitschmid
Operation of Separators
(VA 81/4841/E)

3) J. Decasper
Operation of Tube Mills
(VA 81/4840/E)

4) J. Decasper
How to improve mill performance
(VA 83/5031/E)

5) K. Breitschmid / Hp. Fisch
TECCA Course
Optimization of Grinding Systems
(VA 85/5212/E)

slegten

CHARGES TYPES DEUXIEME CHAMBRE

Selon P.M.
pour un ciment 95% clinker- 5% gypse

M MICHELET

CIRCUIT FERME

BLAINE	2700 - 3000		3200 - 3500		4200 - 5500	
	charge	appoints	charge	appoints	charge	appoints
Ø60 mm	9	25	8,5	25	8,5	26
Ø50 mm	4,5		4		4	
Ø40 mm	3		2,5		2,5	
Ø30 mm	15,5	50	12,4	44	10,8	41
Ø25 mm	28,8		24,65		23,23	
Ø20 mm	19,2	25	16,45	31	15,49	33
Ø17 mm	20		31,5		35,48	
	100%	100%	100%	100%	100%	100%
poids moyen g.	45,31		38,47		36,61	

CIRCUIT OUVERT

BLAINE	2700 - 3000		3200 - 3500		> 3500	
	charge	appoints	charge	appoints	charge	appoints
Ø60 mm	8,5	30	8	29	5	24
Ø50 mm	5		5		4	
Ø40 mm	3		2		2	
Ø30 mm	5,72	32	4,05	28	2,33	22
Ø25 mm	19,44		16,66		11,67	
Ø20 mm	13,89	38	11,91	43	8,33	54
Ø17 mm	18,33		15,71		11	
ø15 mm	26,12		36,67		55,67	
	100%	100%	100%	100%	100%	100%
poids moyen g.	27,61		24,20		19,73	